SOME PHYSICAL AND CHEMICAL CHARACTERISTICS OF ACTON LAKE, OHIO

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Ohio has a paucity of natural lakes, but the number of artificial lakes has been steadily increasing and this trend seems certain to continue into the future. These man-made bodies of water are, and will continue to be, of considerable economic and recreational value. However, if this value is to be fully realized, there must be available basic limnological data for each body of water to provide a basis for sound management practices. A search of the literature has revealed published limnological data for only two of these lakes, Buckeye Lake (Tressler et al., 1940) and Atwood Lake (Wright, 1954).

During the summer of 1959 a general limnological survey of Acton Lake was initiated. This is envisioned as a long-range study to record the changes that take place in a new and relatively small body of water over a number of years. The present paper is a report on some of the physical and chemical characteristics as determined during the first two years of the study.

This study has been made possible by a grant from the Ohio Division of Wildlife, administered through the Institute of Natural Resources of The Ohio State University. Information concerning the soil types and land-use practices within the drainage area were provided by George T. Haynes, Jr. of the U.S. Soil Conservation Service. Mr. Gary Doxtater has contributed greatly in the collection of field data. The contour map of the lake was furnished by the Fish Management Section of the Ohio Division of Wildlife.

THE STUDY AREA

Hueston Woods State Park lies in Butler and Preble Counties in southwestern Ohio about six miles northwest of Oxford. As part of the park development, an earthen dam was constructed across the valley of Four Mile Creek, creating Acton Lake. Dam construction was completed in February, 1957, and the lake was filled to capacity in April, 1957. The resulting body of water is long and narrow in form, following the contours of the flooded stream valley (fig. 1). The watershed supplying the lake is about 104 square miles in area, consisting of the upper drainage of Four Mile Creek. Somewhat over 90 percent of the watershed is in Preble County and the remainder in adjacent Union County, Indiana. The soils of the drainage area are of the Russel Catena series which are fairly fertile. About 20 percent of the watershed is in permanent pasture and woods, chiefly steep slopes, and the remainder principally in corn-meadow rotation. The silt load of Four Mile Creek is extremely variable from year to year, depending on the date and intensity of rainfall, with greatest silting associated with heavy spring rains before crops are established.

The lake has a maximum length, from inflow to dam, of 2.5 miles, a mean width of 0.4 mile, and a shoreline of 8.7 miles. The maximum depth is about 40 ft, and the mean depth about 12.8 ft. The surface encompasses 625 acres; the 10-ft contour, 382 acres; the 20-ft contour, 135 acres; and the 30-ft contour, 20 acres. The volume of the lake, when filled to capacity, is approximately 8,000 ft-acres, with 62 percent contained in the surface to 10-ft depth, 29 percent in the 10- to 20-ft depth, and 9 percent below 20 ft. In order to prevent ice damage to park facilities, the lake level has been lowered about 10 ft each year in mid-November and allowed to refill in late March or early April. This decreases the volume of the lake some 60 percent in winter and, along with the steep slope of much of the shoreline, has probably been a major factor in preventing the establishment of much submerged and emergent vegetation.

METHODS

This paper is based on data collected on 72 days during the periods July 10 to November 7, 1959, and April 22 to November 10, 1960. Data were obtained from three permanent stations, 10, 20, and 30 (fig. 1) and from random points throughout the lake. Unless otherwise stated, data presented in this paper were collected between the hours of 11:00 AM and 1:00 PM from station 30 during the 1960 season.

All water samples were collected with a Kemmerer water sampler. Samples were collected from, at least, the surface and from 10-ft intervals to the bottom. During the period of summer stagnation oxygen concentrations and temperature were frequently determined at 1- or 2-ft intervals within the stratum where values were changing rapidly. Water temperatures were obtained by inserting a glass thermometer into a 250-cc glass bottle and overflowing the bottle several times with water from the desired depth before recording the temperature. Dissolved oxygen was determined by the Alsterberg modification of the Winkler method

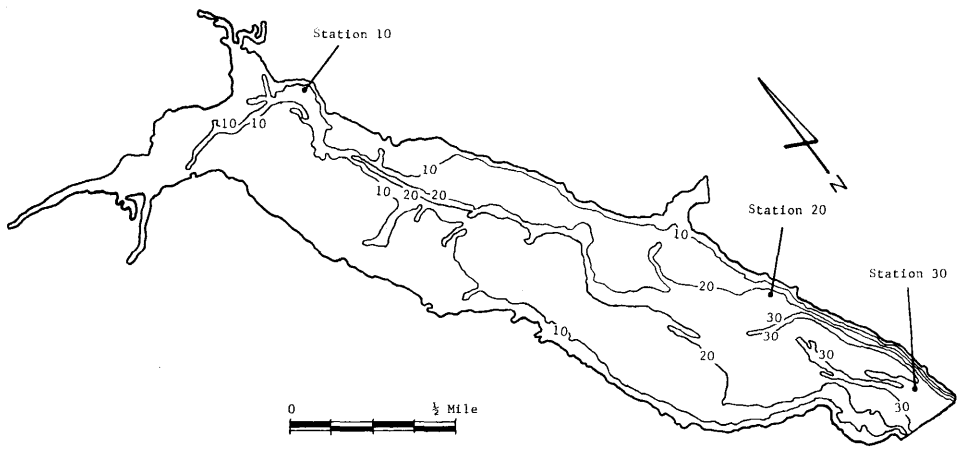

FIGURE 1. Acton Lake, showing depth contours in feet.

American Public Health Association et al., 1949). Free carbon dioxide, phenolphthalein, and methyl orange alkalinity were determined according to the methods outlined by Welch (1948). pH was determined with a Beckman pocket pH meter. Transparency was measured with a standard Secchi disc.

PHYSICAL FACTORS

Water temperature.—Because of its protected position, the lake exhibits strong thermal stratification. Its long axis is from northwest to southeast (fig. 1) and it is well protected from the prevailing westerly and southwesterly winds of the summer period by high ground along its western shore. Only on those rare occasions when the wind is from the northwest or the southeast does it gain full-sweep across the lake.

Thermal stratification was evident by the first week in June, 1960, (tables 1 and 2) and persisted into October of both 1959 and 1960. During the height of thermal stratification, decreases of 3 to 5 degrees Farenheit per foot of increasing depth were frequently present and multiple thermoclines were not uncommon (figs. 2 and 3).

Transparency.—Transparency varied from 64 to 15 in., with maximum values occurring in early spring and summer, and minimum values in late summer and fall (table 1). The days of lowest transparency were not associated with heavy rainfall and consequent heavy silt loads and, due to the lake's protected position, wave action played an insignificant role in influencing the turbidity of the lake. Frequently, the days of low transparency were days on which surface oxygen concentrations were quite high (table 1). Considering the supersaturated oxygen concentrations, and the lack of any other apparent causes, the periods of low transparency were possibly a consequence of large phytoplankton populations. Tressler et al. (1940) and Pearcy (1953) have reported similar transparency minima in late summer and concluded that the major factor was large phytoplankton populations.

CHEMICAL FACTORS

Dissolved oxygen.—The pattern of oxygen distribution in this body of water is that typical of a markedly eutrophic lake. The epilimnion is typically supersaturated during the warmer months (tables 1 and 2). Percent saturation was at a maximum on August 27, 1960, when the surface water was 194 percent saturated.

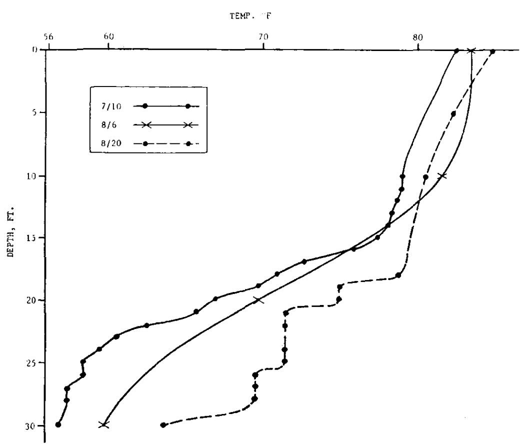

FIGURE 2. Temperature curves, Station 30, 1959.

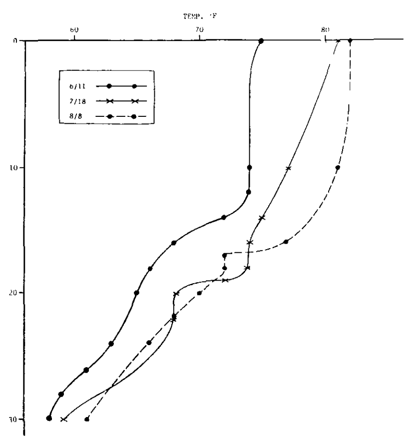

FIGURE 3. Temperature curves, Station 30, 1960.

Hutchinson (1957) states that cases of really marked supersaturation are presumably attributable to photosynthetic activity and Tressler et al. (1940) reported that the highest oxygen concentrations in Buckeye Lake occurred during the periods of highest water temperatures and were a result of large phytoplankton populations.

The dissolved oxygen content of the deeper water became depleted very quickly with the onset of warm weather (tables 1 and 2). Oxygen depletion was evident at a depth of 30 ft by June 2 (0.9 ppm) and was complete from early July until the fall turnover in October. By June 16 dissolved oxygen was virtually exhausted at a depth of 20 ft (0.3 ppm) and was exhausted by September 4. Data were first collected on July 10 in 1959, but the pattern was essentially the same as in 1960 during the latter part of the summer and the fall.

The drop in dissolved oxygen is extremely sharp during the summer stagnation period (fig. 4 and 5). Decreases in concentration approaching 2 ppm per foot of increasing depth were recorded on several occasions.

This severe oxygen depletion is by no means of local occurrence in the lake.

Table 3 gives the concentrations of dissolved oxygen for a number of stations selected randomly along the length of the lake. These, and similar data for other periods, indicate very little or no dissolved oxygen at depths of 16 ft or greater throughout the lake during much of the summer.

Several factors are apparently responsible for this extreme oxygen depletion in Acton Lake. First, the early, sharp, and prolonged thermal stratification, coupled with the lack of effective wave action, prevents the mixing of surface oxygen into the deeper strata of water. Second, the volume of the tropholytic zone is small, compared to the volume of the trophogenic zone. Finally, it is generally agreed that the depletion of oxygen in the deeper waters of a lake is

TABLE 1

Representative physical and chemical data for 0, 20, and 30-ft depths, Station 30, 1960

Date	Temp. °F			O_2 ppm			M.O. alk. ppm		Total alk. ppm		CO_2 ppm			pH		Transparency inches
	0′	20′	30′	0′	20′	30′	0′	30′	0′	30′	0′	20′	30′	0′	30′	
4/22	59	55	55	9.9	9.1	8.5	215	200	215	200	2.0	4.0	5.0	7.9	7.6	64
5/14	59	57	55	7.9	7.6	4.4	—	208	197	208	4.0	6.0	10.0	8.2	7.8	41
6/2	72	64	59	11.0	2.5	0.9	—	202	175	202	—	—	—	8.8	7.8	33
6/16	73	63	61	5.9	0.3	0.1	—	202	179	202	—	—	—	8.5	7.8	—
7/6	79	72	61	10.1	0.7	0.0	162	205	169	205	0.0	4.0	10.0	8.8	7.5	34
7/18	81	68	59	9.0	0.2	0.0	149	246	162	246	0.0	6.0	16.0	8.6	7.8	36
8/3	82	70	61	9.4	0.6	0.0	122	220	131	220	0.0	10.0	19.0	8.6	7.5	29
8/18	82	—	64	12.7	—	0.0	123	236	135	236	0.0	11.0	11.0	8.8	7.4	20
9/4	84	75	66	13.0	0.0	0.0	100	244	117	244	0.0	16.0	34.0	9.0	7.2	15
9/11	75	73	63	4.4	0.0	0.0	133	257	133	257	0.0	13.0	35.0	—	—	31
9/29	75	72	64	8.7	5.2	0.0	140	247	146	247	0.0	5.0	27.0	8.8	7.6	26
10/13	70	66	64	12.9	0.7	0.0	—	267	153	267	—	—	—	9.0	7.8	24
10/27	57	57	57	7.1	6.3	5.5	156	158	156	158	5.0	—	3.0	8.1	8.1	20
11/10	48	—	48	9.7	—	9.7	149	148	149	148	2.0	—	2.0	7.9	7.9	24

TABLE 2

Representative physical and chemical data for 0, 10, and 20-ft depths, Station 20, 1960

Date	Temp. °F			O_2 ppm			M.O. Alk. ppm			Total alk. ppm			CO_2 ppm		pH	
	0′	10′	20′	0′	10′	20′	0′	10′	20′	0′	10′	20′	0′	20′	0′	20′
4/30	61	61	61	10.2	10.2	9.9	189	196	198	189	196	198	1.0	14.0	8.4	8.1
5/14	57	56	56	8.2	7.6	7.8	194	196	199	194	196	199	4.0	8.0	8.4	8.1
5/23	67	66	63	7.3	7.0	6.1	—	—	—	194	206	197	0.0	2.0	—	—
6/4	77	72	64	10.9	8.8	2.4	161	167	201	171	173	201	—	—	8.8	8.0
6/11	75	74	64	10.3	10.0	1.4	—	—	—	178	174	183	—	—	8.8	8.0
6/16	74	74	70	8.6	7.8	1.4	—	—	—	180	185	—	—	—	8.3	8.1
6/28	73	72	66	10.0	8.7	0.9	—	—	—	150	146	196	—	—	8.6	7.7
7/11	79	77	70	11.9	10.9	0.0	152	170	209	163	170	209	0.0	33.0	8.4	7.4
7/18	81	77	70	11.3	6.8	0.3	159	172	215	166	172	215	0.0	12.0	8.4	7.4
7/27	82	81	—	10.8	8.2	—	—	—	—	137	139	169	—	—	8.9	—
8/3	82	81	72	11.2	11.1	—	116	126	146	135	128	146	0.0	10.0	8.7	7.5
8/22	81	79	76	8.4	7.1	0.8	127	135	—	136	138	139	0.0	7.0	8.8	7.8
9/4	82	81	73	13.6	5.0	0.0	102	129	181	122	131	181	0.0	16.0	8.4	7.6
9/11	76	76	74	4.1	4.0	1.8	129	127	167	129	127	167	0.0	12.0	—	—

proportional to the productivity of the lake (Ruttner, 1953; Hutchinson, 1957). The phytoplankton of Acton Lake have not been studied, but a preliminary study of the zooplankton indicates a very productive body of water. (Fisher, 1960).

Carbon dioxide and alkalinity.—With the exception of early spring and autumn, free carbon dioxide was absent from the epilimnion.It was present in concentrations of 10 ppm, or less, during April and May and reappeared in comparable concentrations in October (tables 1 and 2). Its disappearance during the summer was presumably due to photosynthetic activity and was correlated with the appearance of carbonates in small concentrations in the epilimnion.

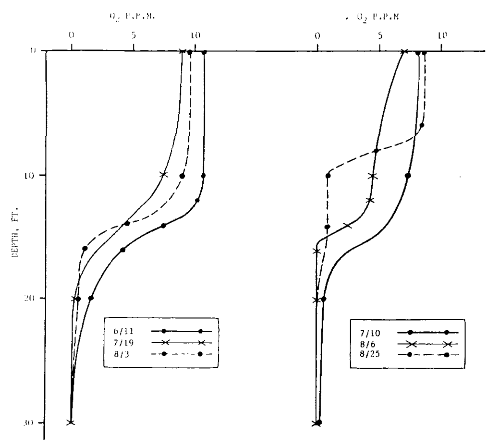

Figure 4. Oxygen curves, Station 30, 1960.
FIGURE 5. Oxygen curves, Station 30, 1959.

TABLE 3
Dissolved oxygen concentrations for random stations, 1960

Date	Station depth ft	Sample depth ft	O_2 ppm
7/1	24	18	0.5
7/1	21	20	0.6
7/6	26	16	1.2
7/7	21	20	0.0
7/11	20	18	0.0
7/18	20	20	0.3
8/3	20	18	0.0
8/11	23	20	0.5
8/22	20	18	0.8
8/26	20	18	0.5

With the development of thermal stratification there was a considerable accumulation of free carbon dioxide in the deeper waters, reaching a maximum in excess of 30 ppm at a depth of 30 ft in early September. This persisted until October.

M. O. alkalinity of the surface water was at a maximum in April (215 ppm) and gradually decreased throughout the summer, reaching a minimum of 100 ppm on September 4 and then increasing to 156 ppm by October 27. During April and May, surface alkalinity was due entirely to the presence of bicarbonates, but small concentrations of carbonates (10 to 23 ppm) were present during June, July, and August. In September carbonates again disappeared from the epilimnion.

Concurrent with the decrease in surface alkalinity, there was an accumulation of bicarbonates in the deeper water (tables 1 and 2). On April 22, 1960, when field work was initiated, surface and 30-ft M. O. alkalinities were 215 and 200 ppm respectively. By October 6 these values were 150 and 266 ppm. This is presumably due to the constant formation of carbonates at the surface and their sinking and conversion to bicarbonates due to the high concentrations of free carbon dioxide in the deeper water. An increase in hypolimnial alkalinity during the anaerobic conditions of summer stagnation may also be due to the reduction of sulfates to sulfides, thereby releasing calcium which can combine with bicarbonates again (Mann, 1958). Mortimer (1942) found that water samples taken from just above the mud showed a steady decline in sulfate content and a steady rise in alkalinity under anaerobic conditions.

In light of the above data, Acton would be classed as a hard water lake and, according to Barett (1952), it would be classed as an alkilitrophic body of water (i.e., methyl-orange alkalinity in excess of 120 to 160 ppm). Phosphate concentrations have not yet been determined for Acton Lake, but other studies (Barett, 1952) would suggest that phosphorus might be in short supply due to the large concentrations of calcium present.

pH.—The pH of the epilimnion was, in general, quite high (tables 1 and 2). In 1960, lowest pH values at the surface (7.9) were recorded in late April and again in early November. From the minimum spring value, surface pH increased throughout the summer, reaching a maximum of 9.0 in early September. With the onset of summer stagnation, and the accumulation of free carbon dioxide, there was a corresponding decrease in the pH of the deeper waters. Minimum pH values (7.2) were present at a depth of 30 ft in early September, corresponding to the epilimnial maximum.

Hydrogen sulfide.—During late summer and early fall, in both 1959 and 1960, the odor of hydrogen sulfide was very pronounced in samples from the deeper strata of water. In 1960 the odor was first detected in a sample from a depth of 30 ft on July 27, and in 1959, on August 13. In 1960 the odor of this gas was detectable in samples from 20 ft by mid-August, and in a sample from 17 ft on September 7.

SUMMARY

This paper describes certain physical and chemical characteristics of Acton Lake, Ohio, on the basis of data collected during 1959 and 1960. The lake exhibited strong thermal and chemical stratification which began to develop in early June and was intensified throughout July, August, and September. During the height of summer stagnation, water temperatures within the thermocline frequently decreased by 3° to 5° F per foot of increasing depth and multiple thermoclines were commonly present. Minimum Secchi disc transparencies occurred during late summer and were probably a consequence of large phytoplankton populations, as evidenced by supersaturated concentrations of oxygen in the epilimnion during this period. Oxygen depletion began to develop in the deeper water concurrently with thermal stratification and there was less than one ppm of dissolved oxygen at depths of 20 ft or more from mid-June until the fall turnover in October. Total alkalinity varied from 117 to 267 ppm, with minimum values occurring at the surface in early September and maximum values at a depth of 30 ft in mid-October. Free carbon dioxide accumulated in the deeper water during the stagnation period, with concentrations exceeding 30 ppm at a depth of 30 ft in September. The odor of hydrogen sulfide was detectable in water from depths of 30 ft by late July, and from depths of 17 ft by

early September. The pH varied from 9.0 to 7.2, with maximum values at the surface and minimum values at a depth of 30 ft in early September.

The sharp thermal stratification is apparently a consequence of the protected position of the lake relative to prevailing westerly and southwesterly winds of the summer period. Thermal stratification, in turn, is a primary factor contributing to the well developed chemical stratification. The rapid depletion of oxygen and the accumulation of high concentrations of free carbon dioxide and bicarbonates, associated with the presence of hydrogen sulfide, in the deeper water must be due to intense biological activity and indicates a highly eutrophic body of water.

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